

Effect of selected bioengineering measures on runoff, soil loss, and cotton (*Gossypium hirsutum* L.) productivity in the semi-arid region of western India

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ARTICLE INFO

Keywords:

Filter strips
Bio-filters
Soil erosion
Vegetative barrier
Nutrient loss
Soil health

ABSTRACT

Soil erosion and associated loss of soil nutrients and organic carbon are one of the major reasons for low crop productivity in major cotton (*Gossypium hirsutum* L.) growing areas of India. This calls for designing acceptable and low-cost bioengineering measures to enhance system productivity and soil health. Thus, a field study was conducted at Vasad, Gujarat, India from 2014 to 2017 to evaluate the efficacy of selected bioengineering treatments on cotton crop production and runoff and soil loss. The eight experimental treatments consisted of bio-filters of three grass species, viz. Para (*Brachiaria mutica*), Guinea (*Megathyrus maximus*), and Napier (*Pennisetum purpureum*) at two strip widths (1 m and 2 m), field bund, and the conventional system as practiced by the farmers of the region. The treatments were tested in 45 × 10 m plots having the gauging facility for recording runoff and soil loss data. Rainfall, runoff, sediment concentration, soil loss, organic carbon, nutrient loss, and growth and yield parameters of grass barrier species and the cotton crop were recorded and analysed. The filter strip of Guinea sp. at 2 m width was most effective, reducing runoff by 30%, soil loss by 66%, nutrients loss by 69%, sediment concentration to 1/3rd, and soil organic carbon loss by 65%. The lowest runoff coefficient value of 0.209 observed among the filter strips in this treatment, indicated about 79% of rainwater was conserved in *situ*. The available soil nutrients increased by up to 42% and SOC concentration by 61%, and cotton equivalent yield by 25% than that of the conventional system. We concluded that Guinea grass filter strips of 2 m width planted at 45 m spacing in cultivable lands having 2% slope minimized runoff, soil loss, nutrient loss, improved soil fertility and enhanced cotton productivity.

1. Introduction

Cotton (*Gossypium hirsutum* L.) is one of the important commercial fiber crops of India and plays a significant role in the Indian economy (CICR Vision, Document, 2050, 2015). Soil erosion is one of the major causes of low productivity (Rao et al., 2015; Lenka et al., 2017; Osh-unsanya et al., 2019) in cotton growing regions of western India.

The cotton growing region in India is characterized by a sub-humid to semi-arid climate with monsoonal high-intensity rains. Cotton is a widely spaced row crop cultivated during the monsoon season and requires frequent inter-cultivation for weed control and better growth

(CICR Vision, Document, 2050, 2015). In these regions, most of the annual rainfall occurs in 30–40 days, distributed between June to September months, out of which about ten rainy days witness high runoff events (Kurothe et al., 2014). The crop is sown, with the moisture from initial monsoonal rains in the first fortnight of July. During the monsoon's peak rainfall period, i.e., July and August, the crop is in the initial stage, and land is not fully covered. This condition accelerates the raindrop splash and sheet erosion, increasing the crop fields' soil and nutrient losses (Rao et al., 2015; Nachimuthu et al., 2018). Such recurrent erosion makes the soils poor in organic carbon, nitrogen, and other plant nutrients, with a severe economic impact on small-scale

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<https://doi.org/10.1016/j.indcrop.2022.115029>

Received 9 February 2022; Received in revised form 25 April 2022; Accepted 30 April 2022

Available online 20 May 2022

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landholding systems. In the absence of suitable erosion control measures, the moderate to high-intensity rains in these soils generate a high volume of runoff, leading to loss of essential soil nutrients and fertile soil sediments and consequently causing pollution and sedimentation in the water bodies (Fan et al., 2015; Rao et al., 2015).

The effect of soil and water conservation structures on resource conservation and productivity enhancement has been studied previously, showing a significant amount of runoff control and positive impact on crop productivity (Fikir et al., 2009; Sharda et al., 2015). The in-situ soil and water conservation measures such as conservation furrow, ridge, and furrow, broad bed and furrow, conservation tillage techniques significantly reduce the runoff and conserve rainwater (Erkossa et al., 2005; Choudhary et al., 2013; Rao et al., 2018). However, they are costly on the part of an individual farmer, and also these techniques are less effective in filtering the sediments and nutrients from the runoff (Dev et al., 2014; Naresh et al., 2014; Patil et al., 2016). The primary reasons for their poor adoption in farm holdings are high cost and loss of a portion of land in the engineering measures. However, bioengineering measures are a better alternative in these small-scale landholdings due to being cost-effective and for their better efficiency in filtering nutrients and soil sediments (Singh et al., 2019; Sheng et al., 2021; Shokri et al., 2021). The vegetative filters on croplands typically consist of wider strips of perennial grass species planted on contours at suitable vertical intervals in contrast to vegetative barriers, which are usually narrow strips of perennial grasses (Blanco-Canqui et al., 2004; Rao et al., 2015; Lenka et al., 2017). These measures are cost-effective and may provide additional benefits in the form of forage and fuel depending upon the choice of the species (Daili et al., 2017).

The Indian studies show that barriers or filter strips of grasses like Vetiver, Saccharum, and locally available natural grasses effectively reduce soil losses from crop fields (Prasad et al., 2005; Sudhishri et al., 2008; Mane et al., 2009; Dass et al., 2011). The suitability of natural grasses such as *Dichanthium annulatum* (Jinjvo) and *Cenchrus ciliaris* (Anjan) have also been tested as a vegetative barrier at a one-meter vertical interval in fields having 2–4% slope (Tiware and Kurothe, 2006). However, studies involving grass species having forage value are limited for Indian conditions. The forage grasses such as Napier, Guinea, and Para grasses are very nutritious, palatable, and high-yielding and are being cultivated in various parts of India for fodder purposes. These grasses may be used as filters to conserve natural resources and meet the fodder requirement. However, information about an appropriate grass (bio) filter species and its design dimensions for the cotton-growing semi-arid regions of western India is non-existent. Further, the extent to which these filters meet the forage needs of the farm holdings and improve farm productivity and soil health is not studied. Keeping these considerations in view, we evaluated various high-value forage grasses as filter strips to minimize soil erosion, augment resource conservation, and enhance cotton productivity in western India.

2. Materials and methods

2.1. Experimental site

The experiment was conducted for three consecutive years during 2014–2017 at the experimental farm of Indian Institute of Soil and Water Conservation (IISWC), Research Centre, Vasad (Latitude: 22.4574°N and Longitude: 73.0806°E), in the Anand district of Gujarat, India. The experimental site is located in the Mahi River catchment area of central Gujarat in Western India, 18 km from District headquarters (Anand) and 80 km from the State capital city (Gandhinagar). The experimental site has a semi-arid climate and is classified as tropical savannah type as per the Koppen-Geiger climate classification system (Peel et al., 2007). The average (last 50 years) annual rainfall at the experimental site is 871 mm, with 94% of the annual rainfall occurring during June to September and 61% during July–August. The average annual maximum and minimum temperatures

are 33.7 °C and 18.9 °C, respectively. Annual pan evaporation is 2119 mm, indicating a large moisture deficit for long periods, and favorable crop growing conditions are constrained to 110–120 days. The soil at the experimental site was characterized by a sandy clay loam texture in the surface layer with the prevalence of surface crusts and is classified as mixed Hyperthermic Typic Fluventic Ustochrepts as per the USDA classification (Soil survey staff, 2014). The site had a very deep soil (more than 1.5 m depth) and was having a crumbly structure with an average bulk density of 1.35 Mg m⁻³ in the 0–150 mm layer. The experiment was conducted in a field of 2% land slope. The plow layer was poor in fertility with oxidizable organic carbon of 0.35 g 100 g⁻¹ by Walkley and Black method, and available N, P₂O₅, and K₂O of 193, 58, and 302 kg ha⁻¹, respectively.

2.2. Experimental setup and treatments

This study conducted in the Agroclimatic Zone 13 (Gujarat Plains and Hills Region) on a well drained, coarse loamy, mixed Hyperthermic Typic Fluventic Ustochrepts soil, tested the effectiveness of forage grass filter strips by planting forage grasses in the downstream border area of the cotton crop fields as bio-filters, with eight experimental treatments (Fig. S1). The treatment details were as follows:

1. Bio-filter of Para (*Brachiaria mutica*) grass at 1 m width (P₁)
2. Bio-filter of Para (*Brachiaria mutica*) grass at 2 m width (P₂)
3. Bio-filter of Guinea (*Megathyrus maximus*) grass at 1 m width (G₁)
4. Bio-filter of Guinea (*Megathyrus maximus*) grass at 2 m width (G₂)
5. Bio-filter of Napier (*Pennisetum purpureum*) grass at 1 m width (N₁)
6. Bio-filter of Napier (*Pennisetum purpureum*) grass at 2 m width (N₂)
7. Field bund on contours (FB) with 45 m spacing and 0.6 m height
8. Control without any bund or conservation measures

The treatments were tested in 45 m long and 10 m wide plots with an automatic gauging facility for recording runoff and soil loss data. These filters were planted at the bottom end of the plots (~45 m interval) in the beginning of the experiment and maintained throughout the entire experimental period. The cotton crop was grown uniformly as a test crop in the plot area of each treatment with the standard package of practices. The standard practice for *kharif* rainfed cotton crop included initial land preparation followed by repeated harrowing and planking before the onset of the monsoon. The crop was sown by hand dibbling of seeds spaced at 0.75 m (row to row and plant to plant). Weeding and inter-cultural operations was done manually with the help of hand hoe and also bullock drawn cultivators. Recommend fertilizers doses (N:P:K@100–50–50 kg ha⁻¹) was applied to the cotton crop. The cotton picking was done manually.

2.3. Data collection and analysis

During the experiment period, data for runoff and sediment samples, biophysical parameters of grass filters, and yield data of cotton crop were collected for each treatment plot. Rainfall amount and intensity data were collected from non-recording and recording rain gauges installed at the research farm, 200 m away from the experimental site.

2.3.1. Runoff

In each treatment plot, the runoff was recorded by an H-flume (Fig. S2) equipped with an automatic stage level recorder in the gauging room. When the flow occurred, the float of the automatic stage level recorder got raised and recorded on the chart as a hydrograph for each rainfall event. The runoff charts were analyzed, and runoff for each treatment was computed. Based on the stage-discharge relationship developed for the given size flume, the measured runoff depth or stage was converted into the flow rate. This flow rate or discharge was converted into the volume unit by multiplying the run off rate with time. This runoff volume was converted into runoff depth by dividing the plot

area (runoff contributing area).

2.3.2. Sediment concentration, soil, nutrients, and carbon loss

On runoff-producing rainy days, runoff samples were collected from the tank connected through the Coshocton wheel equipped with an H flume setup. A portion of the runoff was diverted to the runoff collection tank using the Coshocton wheel sampler placed below the H-flume crest. The 24 h composite runoff samples were collected for determining the sediment concentration, soil, nutrients, and organic carbon losses. The collected runoff samples were filtered and dried at 105 °C, and sediment concentration was determined. A portion of the collected runoff samples was air-dried, and the sediment was analysed for available nitrogen using alkaline KMnO_4 oxidation method (Subbiah and Asija, 1956), available phosphorous by 0.5 M NaHCO_3 extraction method (Olsen et al., 1954), available potassium by neutral normal ammonium acetate extraction method using a flame photometer (Jackson, 1973), and organic carbon concentration by wet oxidation method (Walkley and Black, 1934). The soil, nutrients, and organic carbon losses were calculated based on their concentration and daily runoff volume. The annual soil, nutrients, and organic carbon losses were obtained by adding the daily losses over the crop growing season.

2.3.3. Soil fertility

After the experiment, the soil samples were collected from 0 mm to 150 mm layer of the treatments, with four replications per treatment. These soil samples were analyzed for organic carbon, available nitrogen, phosphorous, and potassium using the standard procedure mentioned in the preceding section (Jackson, 1973) to study the impact of various grassfilter strips on soil fertility.

2.3.4. Growth parameters and yield of forage grasses and test crop (cotton) yield

The growth parameters such as the number of tillers, root volume, circumference of the clump, root diameter were measured in the filter strip treatments. Six clumps under each filter treatment were randomly selected and uprooted at the end of monsoon season (i.e. end of October). Initially the root portion was separated from the clump and after through washing with water and wiping with dry cloths the fresh weight of roots was recorded. The diameter of 20 representative roots per clump was measured with the help of screw gauge and their average radius (r) was calculated. The root volume was measured by immersing fresh roots in a graduated cylinder partially filled with water; the rise in water level was noted as volume of roots (V). Based on these measured data, the soil binding capacity of grasses was worked out by using the following formula (Sudhishri et al., 2008):

$$\text{Soil binding factor}(F) = \frac{V}{r^2}$$

Where, F = soil binding factor.

V =volume of roots (cm^3).

r = average radius of roots (mm),

The growth parameters of forage grasses and cotton yield data were collected from four replicates per treatment. The grass yields of the plots were converted into the cotton equivalent yields based on the market value of fodder grass and cotton in 2019.

2.3.5. Statistical analysis

The data on daily runoff, sediment concentration, soil and nutrients and organic carbon loss was analysed using SPSS version 20.0. The rainfall was common to all the treatments, so the event wise runoff, sediment concentration, soil and nutrients, organic carbon loss from different treatments were compared using the paired t-test. The difference between individual means was compared at the 95% probability level. Data for available nutrients and organic carbon content in soil, grass growth parameters, and yield data of grass filters and cotton crops

were collected from four replications in each treatment. The data were analyzed by randomized block design at $P < 0.05$ level.

3. Results

3.1. Runoff

The yearly rainfall during the experimental period were 1221 mm, 493 mm, and 560 mm during 2014, 2015, and 2016, respectively. The runoff from the experimental period was pooled, analyzed and mean annual runoff and runoff coefficients are presented in Fig. 1. The lowest runoff was observed in the plot treated with field bunds, followed by the plots treated with a 2 m wide Guinea grass filter strip (G_2). The runoff coefficient of treated plots varied from 0.126 under contour field bunds to 0.299 under control. There was a reduction in the runoff coefficient by more than two times in the bunding treatment. Thus, the field bund conserved 87% of the annual rainwater. Among the grass filter strips, the lowest runoff coefficient value of 0.209 was observed in the 2 m wide Guinea grass filter strip, indicating about 79% of rainwater being conserved in-situ. The soil conservation treatments were significantly better than control in reducing runoff (Table 1). On the contrary, field bund treatment was statistically superior to all the treatments in reducing runoff (Table 1). The runoff volume was 60% lower than control in FB and 30% lower in G_2 treatment (Table 1). Among the grass filters, G_2 (which was at par with P_2) was statistically superior to other treatments. The G_1 and G_2 treatments reduced the runoff by 22% and 30%, respectively, whereas the P_1 and P_2 treatments reduced the runoff by 22% and 29%, respectively.

3.2. Sediment concentration

All the treatments (except FB) were significantly better than control in reducing sediment concentration in the runoff (Table 1). The sediment concentration under field bund and control were statistically at par. On the contrary, sediment concentration was lowest under G_2 (Table 1), which was statistically at par with P_2 . Compared over control, there was a reduction in sediment concentration by about two times under grass filters of 1 m width and reduction by three times under grass filters of 2 m width. For instance, the sediment concentration under control was 2.94 g lit^{-1} , which reduced to 1.49 g lit^{-1} under G_1 and 0.98 g lit^{-1} which reduced to 1.49 g lit^{-1} under G_1 and 0.98 g lit^{-1} under G_2 .

Table 1

Effect of soil conservation treatments on runoff, sediment concentration and soil loss from crop (cotton) field (2014–16).

Treatment	Mean runoff (mm)		Mean Sed. con. g lit^{-1}	Mean soil loss (tha^{-1})	
	Daily-Event	Annual		Daily-Event	Annual
Para GFS of 1 m width	16.6c	172.8c	1.50c	0.29c	2.95c
Guinea GFS of 1 m width	16.5c	172.7c	1.49c	0.28c	2.92c
Napier GFS of 1 m width	18.1b	182.9b	1.71b	0.33b	3.55b
Para GFS of 2 m width	15.2e	158.7e	1.01e	0.19e	1.97e
Guinea GFS of 2 m width	15.0e	157.1e	0.98e	0.18e	1.96e
Napier GFS of 2 m width	15.9d	164.1d	1.23d	0.23d	2.40d
Contour field bund	8.6f	96.3f	2.93a	0.29c	2.94c
Control	21.7 a	223.4 a	2.94a	0.55a	5.78a

GFS: grass filter strips; g lit^{-1} : gram per litre; t ha^{-1} : tonnes per hectre-; Sed. Con.: Sediment Concentration; Numbers followed by same alphabets along the column are not significantly different at $p < 0.05$.

3.3. Soil loss

All the treatments were significantly better than the control in minimizing soil loss (Table 1). Among the treatments, the lowest annual soil loss was observed in G₂, which was at par with P₂ (Table 1). The G₂ and FB treatments reduced the annual soil loss by 66% and 49%, respectively, over control. Napier grass filters of 1 m and 2 m width reduced the annual soil loss by 39% and 58%, respectively, over control.

3.4. Nutrient and organic carbon losses

The nutrients (nitrogen, phosphorous, and potassium) and organic carbon losses from various treated plots through runoff showed all treatments to be statistically superior to control (Table 2). The G₂ treatment was statistically better than all treatments in minimizing losses of nutrients and organic carbon (Table 2), which was statistically at par with P₂ (Table 2). Compared to control, the G₂ treatment reduced the annual nitrogen, phosphorous, potassium, and organic carbon losses by 71, 66, 69, and 65%, respectively. The corresponding reduction in the annual nitrogen, phosphorous, potassium, and organic carbon losses under the G₁ treatment over control were 62, 52, 60, and 46%, respectively.

3.5. Soil fertility parameters

The soil fertility parameters (plant-available N, P₂O₅, K₂O, and oxidizable organic carbon of soil) under grass filter strips were significantly better than control plots (Table 3). Among the treatments, soil fertility was statistically better under G₂ or P₂ treatments. The available N, P₂O₅, K₂O, and SOC content under G₂ treatment were higher by 42%, 40%, 30%, and 61%, respectively, over control. The G₁, P₁, and FB treatments were comparable in all the monitored soil fertility parameters.

3.6. Biophysical parameters of grass species

The Guinea and Napier grasses had a significantly higher survival (about 91%) than Para grass, with about 82% survival (Table 4). Significantly the highest number of tillers was observed under G₁ followed by G₂ and then P₁ and P₂ treatments. The basal circumference under G₁ and P₁ were at par and were significantly higher than other treatments. The order of treatments in terms of basal circumference was P₁~G₁ > P₂~G₂ > N₁ > N₂. In general, the number of tillers and basal circumference in 1 m width strips were significantly higher than the 2 m width grass filter strips. The Guinea grass filter strips had a significantly higher soil binding factor than the Para and Napier grass filters. The treatments of Guinea and Napiergrass filter strips at 1 m width resulted insignificantly higher green grass yields (Table 5). Forage grass yield of any species under 2 m wide strips was significantly lower than their corresponding 1 m width strips. In 2015–16, lower grass yields were recorded compared to other years due to less rainfall.

Table 2

Effect of different soil conservation treatments on nutrients and organic carbon loss from the cotton fields (2014–16).

Treatment	Nitrogen loss (kg/ha) Mean		Phosphorous loss (kg/ha) ⁻¹ , Mean		Potassium loss (kg/ha) ⁻¹ Mean		Organic carbon loss (kg/ha) ⁻¹ Mean	
	Daily-Event	Annual	Daily-Event	Annual	Daily-Event	Annual	Daily-Event	Annual
Para GFS of 1 m width	0.27c	2.71c	0.19c	1.64c	0.21c	2.08c	3.94c	38.95c
Guinea GFS of 1 m width	0.27c	2.68c	0.18c	1.62c	0.20c	2.04c	3.86c	37.13c
Napier GFS of 1 m width	0.31b	2.89b	0.21b	1.94b	0.24b	2.38b	4.92b	48.41b
Para GFS of 2 m width	0.20e	2.11e	0.13d	1.2d	0.16d	1.63d	2.40e	24.39e
Guinea GFS of 2 m width	0.19e	2.07e	0.12d	1.14d	0.15d	1.61d	2.38e	23.92e
Napier GFS of 2 m width	0.24d	2.52d	0.19c	1.63c	0.19c	1.97c	3.12d	31.33d
Contour field bund	0.27c	2.70c	0.17c	1.51c	0.20c	2.04c	3.90c	37.97c
Control	0.71a	7.05a	0.34a	3.31a	0.50a	5.12a	6.88a	69.00a

GFS: grass filter strips; kg ha⁻¹: kilogram per hectare ; Numbers followed by same alphabets along the column are not significantly different at p < 0.05.

Table 3

Effect of conservation treatments on soil fertility after 3 years experimentation.

Treatment	Available N (kg ha ⁻¹)	Available P ₂ O ₅ (kg ha ⁻¹)	Available K ₂ O (kg ha ⁻¹)	Organic Carbon Concentration (g kg ⁻¹)
Para GFS of 1 m width	226c	71c	343c	4.4b
Guinea GFS of 1 m width	230c	72bc	345c	4.5b
Napier GFS of 1 m width	197d	68d	326d	4.2c
Para GFS of 2 m width	251a	80a	366a	5.2a
Guinea GFS of 2 m width	256a	81a	368a	5.3a
Napier GFS of 2 m width	240b	74b	351b	4.6b
Contour field bund	228c	72bc	343c	4.5b
Control	177e	58e	283e	3.3d

GFS: grass filter strips; kg ha⁻¹: kilogram hectare – 1; g kg⁻¹: gram per kilo gram, Numbers followed by same alphabets along the column are not significantly different at p < 0.05.

Table 4

Forage grass survival, growth and soil binding factor of various filter strip treatments.

Treatment	Survival %	No. of Tillers	Basal circumference, mm	Soil binding factor
Para GFS of 1 m width	81.75b	51.50c	1290.0a	381.25b
Guinea GFS of 1 m width	91.00a	84.50a	1305.0a	420.00a
NapierGFS of 1 m width	91.00a	36.25e	825.0c	310.75c
Para GFS of 2 m width	81.50b	43.50d	1145.0b	377.75b
Guinea GFS of 2 m width	90.75a	72.25b	1170.0b	418.75a
NapierGFS of 2 m width	90.50a	28.50f	697.5d	295.00c
CD (0.05)	4.17	5.56	73.9	23.18

GFS: grass filter strips; CD: critical difference at 5% significant level Numbers followed by same alphabets along the column are not significantly different at p < 0.05.

3.7. Crop yield

The three years' average cotton equivalent yield (considering the market price of cotton and forage grass) under different treatments varied from 1144 to 1333 kg ha⁻¹ as compared to the control plot yield of 1051 kg ha⁻¹. Among the treatments, FB showed significantly higher

Table 5

Forage grass yields from various filter strip treatments.

Treatment	Green fodder yield (kg ha ⁻¹)			
	2014–15	2015–16	2016–17	Average
Para GFS of 1 m width	1554	1229	1391	1363c
Guinea GFS of 1 m width	2302	1944	2123	2122a
Napier GFS of 1 m width	2275	1960	2117	2112a
Para GFS of 2 m width	1369	1120	1244	1208d
Guinea GFS of 2 m width	2109	1758	1933	1916b
Napier GFS of 2 m width	2135	1742	1939	1915b
CD (0.05)	83.27	79.28	76.26	56.20

GFS: grass filter strips; Kg ha⁻¹: Kilogram per hectare; CD: critical difference at 5% significant level; Numbers followed by same alphabets along the column are not significantly different at $p < 0.05$.

cotton yield, which was at par with G₂. Over the control, the 1 m and 2 m wide Guinea filter strips significantly increased the yields by 18% and 26%, respectively. Lower cotton yields were recorded compared to other years of the experiment due to low rainfall. The cotton yield in 2 m width strips was significantly higher than the 1 m width grass filter strips of respective grasses (Table 6).

4. Discussion

4.1. Runoff, sediment concentration, and soil loss

Our results showed a runoff coefficient of 0.13 under field bund and 0.21 under the best performing bio-filter treatment (G₂), referring to in-situ runoff conservation potential of 87% and 79%, under the two treatments, respectively (Fig. 1). The runoff reduction with Napier grass filters was lower than the Guinea and Para grass filters. In percent terms, the runoff reduction by the best performing grass filter (G₂) was 30% compared to control (Table 1). This value is on a lower side than previous reports due to our experiment site's gentler land slope (Sudhishri et al., 2008; Al-wadaey et al., 2012; Hernandez-Santana et al., 2013; Fan et al., 2015). For instance, the grass barriers in the eastern ghats region of India were effective in reducing runoff by 63% over control (Sudhishri et al., 2008). Al-wadaey et al. (2012) reported that grass filters occupying 4.3% of the area significantly reduced the runoff volume by 64%. Native Prairie filter strips reduced the runoff volume by 37% compared to watersheds with row crops (Hernandez-Santana et al., 2013). The grass hedges decreased surface runoff by 27%–72% in corn fields on slopes with 15% and 20% gradients.

The sediment concentration of runoff samples was significantly lower under grass filter strip treatments of any width than even under field bund treatment (Table 1). Our findings concerning the efficiency of grass barriers in reducing sediment concentration conform with previous workers (Mishra et al., 2006; Rao et al., 2015; Sheng et al., 2021). The surface cover with *Dicanthium annulatum* in watercourses reduced

Table 6

Effect of conservation treatments on cotton equivalent crop yield.

Treatment	Cotton (cotton+ grass equivalent cotton) yields, kg ha ⁻¹			
	2014–15	2015–16	2016–17	Average
Para GFS of 1 m width	1286	1060	1124	1157c
Guinea GFS of 1 m width	1401	1113	1214	1242b
Napier GFS of 1 m width	1268	1053	1111	1144c
Para GFS of 2 m width	1396	1119	1216	1244b
Guinea GFS of 2 m width	1472	1226	1287	1328a
Napier GFS of 2 m width	1394	1126	1222	1247b
Contour field bund	1466	1238	1295	1333a
Control	1177	956	1021	1051d
CD (0.05)	52.10	45.05	38.77	25.33

GFS: grass filter strips; kg ha⁻¹: kilogram per hectare; CD: critical difference at 5% significant level; Numbers followed by same alphabets along the column are not significantly different at $p < 0.05$.

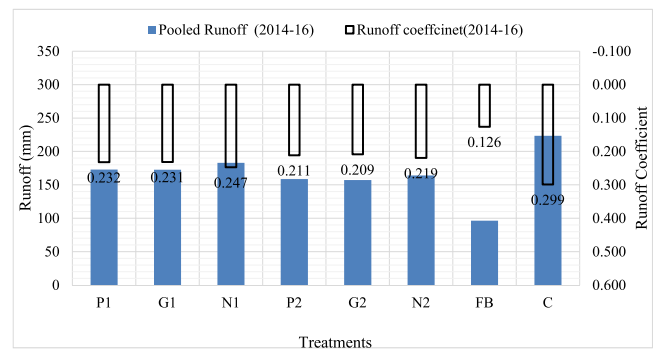


Fig. 1. Pooled data on runoff (mm) and runoff coefficient under various soil conservation treatments. P₁: Para grass filter strips of 1 m width, G₁: Guinea grass filter strips of 1 m width, N₁: Napier grass filter strips of 1 m width, P₂: Para grass filter strips of 1 m width, G₂: Guinea grass filter strips of 2 m width, N₂: Napier grass filter strips of 2 m width, FB: Field bund, C: Control.

the sediment concentration in runoff water by 5.7 times in the same study region (Rao et al., 2015). The natural vegetation as buffer strips in sloping lands of the North-Eastern part of India reduced the sediment concentration five times (Lenka et al., 2017). The filter strips reduce the sediment concentration by decreasing the flow velocity and thereby deposition of sediments (Rao et al., 2015). Vegetative barriers act as a filter by increasing surface roughness, which augments infiltration by decreasing flow volumes and velocity (Sudishri et al., 2008; Borin et al., 2010).

The strip width is one of the main controlling variables controlling runoff behavior (Abu-Zreig et al., 2004; Lenka et al., 2012; Hou et al., 2019). This study revealed that grass species' morphology and growth behavior and grass strips' width/flow path influenced the runoff. A lower sediment concentration resulted in overall soil loss significantly lower in the filter treatments of 2 m width (Table 1). The Guinea and Para grass filter strips of 2 m width in croplands generated significantly the lowest sediment concentration and significantly lower soil loss (66% reduction over the control). In contrast, field bunds yielded the lowest runoff (60% reduction over the control) but not the lowest soil loss (49% reduction over the control). Such effect was observed due to higher sediment concentration in runoff under field bund treatments. In other words, field bunds were effective in runoff reduction and rainwater conservation, but grass filters were more effective in filtering the runoff water, reducing the flow velocity and thereby sediment deposition, and minimizing the soil loss from croplands. The vegetation dynamics, mainly through vertical saturated hydraulic conductivity, stem spacing, and strip Manning's roughness, affect the runoff and sediment trapping by the vegetative filter strips (Daili et al., 2017; Hou et al., 2019).

The difference in soil conservation and filtering efficiency of different bio-filters was primarily due to the growth and tillering behavior of grass species (Sheng et al., 2021). Guinea and Para grass species had a higher number of tillers (Table 4) and higher basal circumference. These grass filter species also showed an excellent binding factor of more than 200 (Sudhishri et al., 2008). The higher number of tillers, basal circumference, and soil binding factor enabled Guinea and Para grass filter strips to have better resource conservation potential in the runoff, soil, nutrients, and organic carbon losses. Sudishri et al. (2008) also reported that better growth parameters and binding factors made Sachharum and Vetiver the most effective grass species in reducing runoff and soil and organic carbon losses in eastern India.

Efficacy of grass and vegetation barriers in significantly reducing soil erosion has been reported from different agroclimatic zones of India (Sudhishri et al., 2008; Dass et al., 2011; Lenka et al., 2012; Lenka et al., 2017). Vegetation restoration in the Yanhe watershed, the Chinese Loess Plateau, has positively impacted soil erosion reduction (Wen et al., 2019).

4.2. Soil fertility and crop productivity

A lower soil loss also resulted in less nutrients and organic carbon loss among the treatment under Guinea and Para grass filter strips of 2 m width. The findings confirm previous studies (Sudhishri et al., 2008; Dass et al., 2011; Zhou et al., 2014; Hou et al., 2018; Oshunsanya et al., 2019). Significant reduction in nutrient and organic carbon losses (Table 2) consequently showed better soil fertility after the three years of experimentation (Table 3), which translated to significantly higher cotton equivalent yield (Table 6) (Huang et al., 2019). The forage grass production was considered an added benefit to maintaining the hedges for soil erosion control. The corn silage crop with palisade grass intercrop was the most viable option for an integrated crop-livestock system for enhancing productivity and nutrient cycling (Pariz et al., 2017). The grass filters in croplands conserve natural resources, control soil erosion, and produce forage for livestock of smallholder farmers of India. Thus, our study clearly showed these filters could reduce the non-point source pollutants from croplands and minimize downstream water bodies' sedimentation.

The cotton yield in 2 m width strips was significantly higher than in the 1 m width grass filter strips of respective grasses. This was mainly because of Guinea filter strips' substantially higher conservation efficiency in terms of lower runoff, lower loss of soil and nutrients from the croplands, and better availability of nutrients for the associated cotton crop. Similar findings were reported by Dass et al. (2011), where the yield of finger millet increased by 18% for lemongrass barriers to 34% for Sambuta barriers in Eastern India. The Vetiver grass hedgerows (VGH) across the slope in cornfield significantly reduce nutrient losses and consequently increase crop yields. The plots treated with field bunding and 2 m width Guinea grass filter strips had a similar effect on crop yields. The results of our study can be extended to other cotton growing countries such as Australia, China and Brazil, with similar climate and soil type and witnessing soil erosion problems, for enhanced cotton productivity (Nachimuthu et al., 2018).

5. Conclusions

This three years' study conducted in a rainfed region with land slope of 2 per cent, clearly showed that the Guinea grass filter strips of 2 m width at 45 m spacing in croplands significantly reduced the sediment concentration, soil loss, nutrients, and organic carbon losses and improved the soil fertility status. Field bunds in croplands were more effective in comparison to forage grass filters of 2 m width in reducing the runoff and increasing in-situ rainwater conservation but not so effective in reducing soil, nutrients and organic carbon losses. The filter induced reduction in the runoff flow velocity facilitated sediment deposition thereby reduced the soil, nutrients, and organic carbon losses, which manifested into improved soil fertility and higher productivity. The integration of perennial fodder grasses in rainfed cropland production systems was found very promising in terms of additional forage production, resource conservation and overall system productivity. The Guinea grass was found superior in terms of resource conservation and system productivity and therefore can be recommended for large number of small and marginal farmers of semiarid conditions. The combination of Guinea grass with rainfed cotton crop can be a useful component of crop-livestock production systems in India and other cotton growing countries.

CRedit authorship contribution statement

All authors contributed to the study. B. Krishna Rao: conducted the study, analyzed the data, prepared the manuscript. reviewed and edited the manuscript; Gaurav Singh, V.C. Pande, D. Dinesh were involved in conducting the study, Gopal Kumar was involved in conducted the study, reviewed and edited the manuscript. N.K. Lenka was involved in preparation of manuscript and also reviewed and edited the manuscript,

P.K. Mishra was involved in conceptualizing the methodology and supervised the study, A.K. Singh was involved in preparation of manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are thankful to Sh Anand Kumar, Technical Officer, Sh. K. D. Mayawanshi, D.G. Damor, Technicians, and other field staff of ICAR-IISWC, RC, Vasad for assistance in collecting the data. The authors were thankful to Dr. Gururaja Rao, Head ICAR-CSSRI, RS, Bharuch, for providing facilities for nutrient analysis. The authors are also grateful to Dr. M. Anuradha, Principal Scientist & Head ICAR-CTRI, RS, Kandukur, Andhra Pradesh, for statistical analysis. We also acknowledge the Head, ICAR-IISWC, RC, Vasad, and Director, ICAR-IISWC, for providing facilities for this study.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.indcrop.2022.115029.

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